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Translation of JP 2004-111870 A

[Title of the Invention]

SEMICONDUCTOR DEVICE AND METHOD FOR PRODUCING THE SAME

[Claim(s)]

[Claim 1]

A semiconductor device characterized by including

an organic-semiconductor layer,

a first and a second electrodes which are in contact with the organic-semiconductor layer and are opposed to each other,

an electric-field-concentrating-shaped portion disposed on at least one electrodes of the first and second electrodes and having a shape generating a concentrated electric-field between the electric-field-concentrating-shaped portion and the other electrode.

[Claim 2]

The semiconductor device according to claim 1, characterized by further including a gate electrode opposed to the organic-semiconductor layer between the first electrode and the second electrode.

[Claim 3]

The semiconductor device according to claim 1 or 2, characterized by that the electric-field-concentrating-shaped portion includes a protrusion protruding from either the first or second electrode toward another electrode.

[Claim 4]

The semiconductor device according to claim 3, characterized by that the protrusion has a head shape.

[Claim 5]

The semiconductor device according to claim 3 or 4, characterized by that the protrusion formed in either the first or second electrode containing a nanotube or nanowire whose head is turned to another electrode.

[Claim 6]

The semiconductor device according to one of claims 3 to 5, characterized by that

the first and second electrodes respectively have the protrusions, and the protrusions are opposed to each other.

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[Claim 7]

The semiconductor device according to one of claims 1 to 5, characterized by that

the electric-field-concentrating-shaped portion has a plurality of first protrusions protruding from the first electrode to the second electrode and a plurality of second protrusions protruding from the second electrode to the first electrode, and

the first protrusions and the second protrusions are opposed to each other.

[Claim 8]

The semiconductor device according to one of claims 1 to 5, characterized by that

the first electrode has a first protrusion protruding toward the second electrode and a first flat part opposed to the second electrode, and

the second electrode has a second protrusion protruding toward the first electrode and a second flat part opposed to the first electrode.

[Claim 9]

The semiconductor device according to one of claims 1 to 8 characterized by that

a plurality of electric-field concentrating regions are disposed discretely between the first and the second electrodes.

[Claim 10]

The semiconductor device according to one of claims 1 to 6, characterized by including two pairs of the first and second electrodes, and

a opposing direction of one of the pair of the first and second electrodes and a opposing direction of another pair of the first and second electrodes are crossing.

[Claim 11]

The semiconductor device according to one of claims 1 to 10, characterized by

the organic-semiconductor layer is made of at least one organic-semiconductor material selected from the group consisting of pentacene, oligo thiophene, oligo thiophene having a substituent, bis-dithieno thiophene, dialkyl anthra dithiophen having a substituent, metal phthalocyanine, fluorinated copper-phthalocyanine, N,N'-dialkyl-naphthalene-1,4,5,8-tetracarboxylic acid diimide substitution product, 3,4,9,10-perylene tetracarboxylic acid dianhydride, N,N'-dialkyl-3,4,9,10-

perylene tetracarboxylic acid diimide, fullerene, regio regular poly, and poly-9,9'-dialkylfluorene-cobithiophene.

[Claim 12]

The semiconductor device according to one of claims 1 to 11, characterized by that

the first and second electrodes are made of at least one conductive material selecting from a group consisting of gold, platinum, silver, magnesium, indium, copper, aluminum, lithium, indium oxide, tin oxide, zinc oxide, lithium oxide, and lithium fluoride.

[Claim 13]

A method of manufacturing a semiconductor device characterized by comprising steps of:

forming an organic-semiconductor layer,

forming first and second electrodes having an electric-field-concentrating-shaped portion disposed on at least one electrodes of the first and second electrodes and having a shape generating a concentrated electric-field between the electric-field-concentrating-shaped portion and the other electrode, and

forming a gate electrode opposed to the organic-semiconductor layer between the first electrode and the second electrode.

[Claim 14]

The method of manufacturing a semiconductor device according to claim 13, characterized by further including a step of heat-treating the organic-semiconductor layer after the step of forming the organic-semiconductor layer.

[Detailed Description of the Invention]

[0001]

[Field of the Invention]

This invention relates to a semiconductor device and a method of manufacturing the same, more specifically, relates to a field-effect transistor using an organic semiconductor and a method of manufacturing the same.

[0002]

[Description of the Prior Art]

In recent years, the attention to an organic thin film field effect transistor is increasing. In an organic thin film field effect transistor, for example, a gate insulating film, one pair of the source / drain electrodes, and an organic-semiconductor layer are formed on a gate electrode in this order. A drain current flows the semiconductor layer between the source / drain electrodes by making a gate electrode into suitable potential and applying a suitable voltage (drain voltage) between one pair of the source / drain electrodes.

[0003]

Since the carrier density of the organic-semiconductor layer is small, in order to enlarge the current which flows between one pair of the source / drain electrodes, the current is subjected to flow wide area in the organic-semiconductor layer.

Figure 14 is an illustrative top view showing the configuration of the source / drain electrodes of the conventional semiconductor device (organic thin film field-effect transistor) 70 containing an organic semiconductor. In figure 14, the organic-semiconductor layer is not shown.

[0004]

One pair of the source / drain electrodes 72 and 73 having comb-shape is formed on gate oxide film 71 so that the source electrode and the drain electrode are arranged to fit with each other with slight space. The source / drain electrode 72 and the source / drain electrode 73 are arranged so that the space between them are almost constant in the area that these electrodes are opposed.

If a gate electrode (not shown) is set to suitable potential, a drain current will flow in the organic-semiconductor layer corresponding to the field between the source / drain electrode 72 and the source / drain electrode 73. Since a drain current flows the wide field in the organic-

semiconductor layer, big current as total flows between one pair of the source / drain electrodes 72 and 73.

[0005]

Moreover, one pair of parallel plate electrodes arranged parallel with each other might be used instead of the electrode of the source / drain electrodes 72 and 73 having comb-shape. In this case, it is designed so that the current flows evenly and stably between one pair of parallel plate electrodes. The semiconductor device equipped with such parallel plate electrodes is disclosed by the following nonpatent literature 1.

[0006]

[Nonpatent literature 1]

Chemistry 2001, vol.56, No.10 p.21

[0007]

[Problem(s) to be Solved by the Invention]

However, the formation field of the source / drain electrodes 72 and 73 becomes large by making the source / drain electrodes 72 and 73 into comb-shape. For this reason, the miniaturization of the device was difficult. Moreover, if spacing between one pair of the source / drain electrodes 72 and 73 having comb-shape is narrowed, the magnitude of the drain current at normal state is greatly dependent on a drain voltage and not stable, and produce the problem that a large ON/OFF ratio cannot be taken.

[0008]

Then, the object of this invention is offering a semiconductor device containing a organic semiconductor which can be miniaturized.

Other object of this invention is offering a semiconductor device containing a organic semiconductor which can take a large ON/OFF ratio even if space between the source / drain electrodes is narrowed.

Another object of this invention is offering a method for manufacturing a semiconductor device which can be miniaturized and contains the organic semiconductor.

[0009]

Yet another object of this invention is offering a semiconductor device containing organic semiconductor which can take a large ON/OFF ratio even if the space between the source / drain electrodes is narrowed.

[0010]

[The means for solving a technical problem and an effect of the inventi

on]

Invention according to claim 1 for solving the above-mentioned technical problem is a semiconductor device (1, 15, 20A-20C, 27, 29, 31, 35A-35D, 40, 50) characterized by including an organic-semiconductor layer (8, 44, 51), a first and a second electrodes (7A, 7B, 21A, 21B, 25A, 25B, 28A, 28B, 30A, 30B, 32A, 32B, 37A, 37B, 45A, 45B, 52A, 52B, 11S, 11D, 23S, 23D, 38S, 38D) which are in contact with the organic-semiconductor layer and are opposed to each other, an electric-field-concentrating-shaped portion (7p, 11p, 16p, 21p, 23p, 25p, 28p, 30p, 32p, 36, 52p) disposed on at least one electrodes of the first and second electrodes and having a shape generating a concentrated electric-field between the electric-field-concentrating-shaped portion and the other electrode.

[0011]

In addition, the numbers in a parenthesis shows the relative elements in the below-mentioned embodiments. This also applies in this term.

For example, the electric-field-concentrating-shaped portion can be made into a configuration in which spacing with another electrode becomes short, compared with other area, in the area that the first electrode and the second electrode are opposed.

According to this invention, if a voltage is applied between the first and second electrodes, concentration of electric field will arise near the electric-field-concentrating-shaped portion formed in at least one of the first and second electrodes. That is, near the electric-field-concentrating-shaped portion, electric field stronger than the other area will arise. Thus, the carrier is intensively injected through the electric-field-concentrating-shaped portion by centralizing electric field positively. Therefore, even when the voltage between the first and the second electrodes is low, a big current flows in the organic-semiconductor layer.

[0012]

Thereby, as compared with the source / drain electrode having comb-shape of the conventional organic thin film field-effect transistor, the formation area of the first and second electrodes can be made small. Therefore, the semiconductor device equipped with the first electrode and second electrodes having such the electric-field-concentrating-shaped portion can be miniaturized.

This semiconductor device may be various kinds of diodes,

transistors, and organic EL devices.

[0013]

Invention according to claim 2 is a semiconductor device (1, 15, 20A-20C, 27, 29, 31, 35A-35D, 40, 50) according to claim 1 characterized by further including a gate electrode (2, 42, 53) opposed to the organic-semiconductor layer between the first electrode and the second electrodes.

According to this invention, a current can flow between the first electrode and the second electrode through the organic-semiconductor layer by making the gate electrode into suitable potential and applying a suitable voltage between the first and second electrodes. That is, this semiconductor device functions as a field-effect transistor.

[0014]

The gate electrode and the organic-semiconductor layer may counter on both sides of the insulator layer.

Either the first electrode or the second electrode may be a source electrode, and another electrode may be a drain electrode. The first and second electrodes may be bottom-contact type or top-contact type.

Experiments have shown that even if spacing between the electric-field-concentrating-shaped portion and another electrode was narrowed, the semiconductor device could achieve a large ON/OFF ratio.

[0015]

As described in claim 3, the electric-field-concentrating-shaped portion may contain the protrusion (7p, 11p, 16p, 21p, 23p, 25p, 28p, 30p, 32p, 36, 52p) protruding from either the first electrode or the second electrode to another electrode, for example.

In the part in which a protrusion exists, spacing between the first and second electrodes can become narrow compared with other parts. Thereby, electric field can be centralized near the head of a protrusion.

[0016]

Moreover, it is desirable that spacing between the above-mentioned protrusion formed in either the first electrode or the second electrode and another electrode is 1 micrometer or less. Thereby, the electric field can be centralized near the head of a protrusion, and the miniaturization of a semiconductor device can be attained by making the formation field of the first and second electrodes small.

As described in claim 4,the protrusion may have a head configuration, for example. Especially, as for the protrusion, the tapering shape (for

example, tip shape) in which width becomes narrow gradually toward the head (another electrode side). In this case, it is desirable that the radius of curvature at the head of the protrusion is made as small as possible, and thereby, electric field can be centralized near the head of the protrusion more effectively and more positively.

[0017]

Moreover, the configuration of the protrusion may have almost fixed width.

Invention according to claim 5 is a semiconductor device (35A-35D) according to claim 3 or 4 characterized by that the protrusion formed in either the first or second electrode containing a nanotube (36) or nanowire whose head is turned to another electrode.

The nanotube is a extra-thin tubular object having a diameter of nanometer (nm) order. Electric field concentrates effectively at the head of the nanotube turned to another electrode.

[0018]

Only one nanotube or a plurality of nanotubes may be formed in the first electrode and the second electrode. Moreover, the nanotube may be formed in either the first electrode or the second electrode, or may be formed in both of them.

Example of the nanotube includes a carbon nanotube and a titania nanotube. That is, the carbon nanotube may be formed in either or both the first electrode and the second electrode, and the titania nanotube may be formed in them instead of the carbon nanotube or with the carbon nanotube.

[0019]

A nanotube can be connected to the first electrode and the second electrode by an electrophoresis method.

A nanowire is an extra-thin wire-like object having a diameter of nanometer (nm) order. Electric field concentrates at the head of the nanowire turned to the another electrode effectively as well as the nanotube. The nanowire can be made of a conductive material used as electrode material, such as gold (Au), platinum (Pt), and silver (Ag).

[0020]

Invention according to claim 6 is a semiconductor device (1, 15, 20A, 27, 29, 31, 35A-35C, 50) according to one of claims 3 to 5, characterized by that the first and second electrodes respectively have the protrusions (7p,

16p, 21p, 28p, 30p, 32p, 36, 52p), and the protrusions are opposed to each other.

According to this invention, electric field can be centralized between the protrusions formed in the first electrode and the protrusion formed in the second electrode. Therefore, since it is possible to make the current concentrate in narrow area in the organic semiconductor layer, the miniaturization of the semiconductor device can be attained by making the formation field of the first electrode and the second electrode small.

[0021]

Invention according to claim 7 is a semiconductor device (20A, 27, 29, 31, 35C) according to one of claims 1 to 5 characterized by that the electric-field-concentrating-shaped portion has a plurality of first protrusions (21p, 28p, 30p, 32p, 36) protruding from the first electrode to the second electrode and a plurality of second protrusions (21p, 28p, 30p, 32p, 36) protruding from the second electrode to the first electrode, and the first protrusions and the second protrusions are opposed to each other.

[0022]

According to this invention, a big current can be flowed between a plurality of the first protrusions formed in the first electrode and a plurality of second protrusions formed in the second electrode. Therefore, the current which flows between the first electrode and the second electrode can be enlarged as total.

Invention according to claim 8 is a semiconductor device (20C) according to claim 1 to 5, characterized by that the first electrode(25A) has a first protrusion (25p) protruding toward the second electrode (25B) and a first flat part (25f) opposed to the second electrode, and the second electrode has a second protrusion (25p) protruding toward the first electrode and a second flat part (25f) opposed to the first electrode.

[0023]

If the protrusion is formed in either the first electrode or the second electrode to which a carrier is injected, the current can be enlarged efficiently. The electrode to which a carrier is injected is determined by the magnitude relation of the potential between the first electrode and the second electrode, and by main carrier in an organic-semiconductor layer.

According to this invention, a current can flow between the first protrusion and the second flat part and between the second protrusion and the first flat part. Therefore, even when the either the first electrode or

the second electrode to which a carrier is injected is reversed, a current can be enlarged efficiently since a carrier is injected in either the first protrusion or the second protrusion.

[0024]

Invention according to claim 9 is a semiconductor device (20A-20C, 27, 29, 31, 35A-35D) according to one of claims 1 to 8 characterized by that a plurality of electric-field concentrating regions are disposed discretely between the first and the second electrodes.

According to this invention, a current can flow in the electric-field concentrating regions disposed discretely. Therefore, the current which flows between the first electrode and the second electrode can be enlarged as total.

[0025]

Invention according to claim 10 is a semiconductor device (15) according to one of claims 1 to 6, characterized by including two pairs of the first electrodes (16A, 17A) and second electrodes (16B, 17B), and a opposing direction of one of the pair of the first and second electrodes and a opposing direction of another pair of the first and second electrodes are crossing.

According to this invention, the current value which flows between the first electrode and the second electrode can be measured by hall effect measurement by measuring the potential difference between one pair of the first electrode and the second electrodes, while arranging the semiconductor device in a suitable magnetic field, and applying an voltage between another pair of the first electrode and the second electrode, and making a gate electrode into suitable potential, thereby making current flow between the pair of the electrodes. Thereby, the carrier mobility in the organic layer can be measured.

[0026]

The organic-semiconductor material that constitutes an organic-semiconductor layer is not especially limited. A well-known material of low-molecular and macromolecule of π-conjugated system can be used. For example, as described in claim 11, the organic-semiconductor layer can be made of at least one organic-semiconductor material selected from the group consisting of pentacene, oligo thiophene, oligo thiophene having a substituent, bis-dithieno thiophene, dialkyl anthra dithiophen having a substituent, metal phthalocyanine, fluorinated copper-phthalocyanine, N,N'-dialkyl-naphthalene-1,4,5,8-tetracarboxylic acid diimide substitution

product, 3,4,9,10-perylene tetracarboxylic acid dianhydride, N,N'-dialkyl-3,4,9,10-perylene tetracarboxylic acid diimide, fullerene, regio regular poly, and poly-9,9'-dialkylfluorene-cobithiophene.

[0027]

The organic-semiconductor material is preferably oligomer. Since oligomer is easy to refine, and since it is easy to obtain oligomer that molecular weight is equal, it can make the organic-semiconductor layer uniform.

As described in claim 12, the first electrode and the second electrode can be made of at least one conductive material selecting from a group consisting of gold, platinum, silver, magnesium, indium, copper, aluminum, lithium, indium oxide, tin oxide, zinc oxide, lithium oxide, and lithium fluoride.

[0028]

The first electrode and the second electrode may be made of only one kind of these conductive materials. The first electrode and the second electrode may be made of two or more kinds of these conductive materials. For example, the first electrode and the second electrode may be made of an alloy of magnesium (Mg) and silver (Ag), an alloy of magnesium and indium (In), an alloy of magnesium and copper (Cu), an alloy of aluminum (Al) and lithium (Li), a composite material of aluminum and lithium fluoride (LiF), a composite material of aluminum and lithium oxide (LiO_2), a solid solution (so-called ITO) of indium oxide (In_2O_3) and tin oxide (SnO_2), a solid solution of indium oxide and a zinc oxide (ZnO), etc.

[0029]

The first electrode and the second electrode may be made of same conductive material or may be made of different conductive material. Moreover, whole of the first electrode and the second electrode may be made of same conductive material, of the electrodes may include different conductive material. For example, the part contacting the insulator layer may be made of titanium (Ti), and the other part may be made of platinum (Pt). Furthermore, the electric-field-concentrating-shaped portion and the other part of the first electrode and the second electrode may be made of different materials.

[0030]

The invention according to claim 13 is a method of manufacturing a semiconductor device (1, 15, 20A-20C, 27, 29, 31, 35A-35D, 40, 50)

characterized by comprising steps of: forming an organic-semiconductor layer(8, 44, 51), forming first and second electrodes (7A, 7B, 21A, 21B, 25A, 25B, 28A, 28B, 30A, 30B, 32A, 32B, 37A, 37B, 45A, 45B, 52A, 52B, 11S, 11D, 23S, 23D, 38S, 38D) having an electric-field-concentrating-shaped portion (7p, 11p, 16p, 21p, 23p, 25p, 28p, 30p, 32p, 36, 52p) disposed on at least one electrodes of the first and second electrodes and having a shape generating a concentrated electric-field between the electric-field-concentrating-shaped portion and the other electrode, forming a gate insulating layer (3, 43, 55) adjacent to the organic semiconductor layer between the first electrode and second electrode, and forming a gate electrode (2, 42, 53) opposed to the organic-semiconductor layer between the first electrode and the second electrode.

[0031]

By this invention, a semiconductor device according to claim 2 can be obtained.

For example, the step of forming the first electrode and the second electrode equipped with the electric-field-concentrating-shaped portion may include a step of forming the electrode film that is made of the material of the first electrode and the second electrode by spatter, for example, and a step of removing the electrode film with leaving a predetermined portion. The step of removing the electrode film with leaving a predetermined portion, for example, may be done by exposuring the electrode film with Electron Beam (EB) and then performing ion-milling.

[0032]

Invention according to claim 14 is a method of manufacturing a semiconductor device according to claim 13, characterized by further including a step of heat-treating the organic-semiconductor layer after the step of forming the organic-semiconductor layer.

According to this invention, by the heat treatment, an unnecessary thing (the thing what does not contribute to conductivity, or what has a small contribution to conductivity) among the organic molecules contained in the organic-semiconductor layer can be evaporated, and the molecule of an organic semiconductor can be made to arrange in the specific arrangement (orientation).

[0033]

The organic-semiconductor layer is preferably made of chained oligomer (for example, thiophene-based oligomer). In this case, molecules

can be made to arrange easily by heat treatment. Heat treatment temperature can be set to, for example, a temperature that is 5 C° to 10 C° lower than melting point (glass transition temperature) of the material which constitutes the organic-semiconductor layer. At such temperature, molecular motion becomes active and chained oligomer is arranged for a short time.

[0034]

The mobility of an organic-semiconductor layer can be raised according to the above effect.

[0035]

[Embodiment of the Invention]

Below, embodiments of this invention are explained to a detail with reference to accompanying figures.

Figure 1 is the illustrative sectional view showing the structure of the semiconductor device concerning the first embodiment of this invention. The semiconductor device 1 is an organic thin film field effect transistor (OFET). Gate oxide film 3 made of silicon oxide, one pair of the source / drain electrodes 7A and 7B, and organic-semiconductor layer 8 are formed in this order on the gate electrode 2 made of silicon that is made to be conductive by a dope of impurities.

[0036]

Gate oxide 3 is formed on whole surface of the gate electrode 2. The source / drain electrodes 7A and 7B are opposed to each other with a gap. The organic-semiconductor layer 8 is formed on gate oxide 3, and the source / drain electrodes 7A and 7B so as to fill the gap between the source / drain electrode 7A and the source / drain electrode 7B. In other words, the source / drain electrode 7A and the source / drain electrode 7B are opposed to each across the organic-semiconductor layer 8.

[0037]

The source / drain electrodes 7A and 7B can be made of at least one conductive materials selecting from group consisting of gold (Au), platinum (Pt), silver (Ag), magnesium (Mg), indium (In), copper (Cu), aluminum (Al), lithium (Li), indium oxide (In_2O_3), tin oxide (SnO_2), zinc oxide (ZnO), lithium oxide (Li_2O), and lithium fluoride (LiF).

[0038]

The source / drain electrodes 7A and 7B may be made of one kind of these conductive materials. The first electrode and the second electrode

may be made of two or more kinds of these conductive materials. For example, the first electrode and the second electrode may be made of an alloy of magnesium and silver, an alloy of magnesium and indium, an alloy of magnesium and copper, an alloy of aluminum and lithium, a composite material of aluminum and lithium fluoride, a composite material of aluminum and lithium oxide, a solid solution (so-called ITO) of indium oxide and tin oxide, a solid solution of indium oxide and a zinc oxide, etc.

[0039]

In this embodiment, the source / drain electrodes 7A and 7B contain the titanium layer 5 adjacent and formed on gate oxide 3, and the platinum layer 6 formed on the titanium layer 5. By the titanium layer, the adhesion of gate oxide 3 and the source / drain electrodes 7A and 7B is improving. The organic-semiconductor material that constitutes an organic-semiconductor layer 8 is not especially limited. A well-known material of low-molecular and macromolecule of π-conjugated system can be used. For example, the organic-semiconductor layer can be made of one or two or more selected from pentacene, oligo thiophene, oligo thiophene having a substituent, bis-dithieno thiophene, dialkyl anthra dithiophen having a substituent, metal phthalocyanine, fluorinated copper-phthalocyanine, N,N'-dialkyl-naphthalene-1,4,5,8-tetracarboxylic acid diimide substitution product, 3,4,9,10-perylene tetracarboxylic acid dianhydride, N,N'-dialkyl-3,4,9,10-perylene tetracarboxylic acid diimide,π-conjugated low-molecular such as fullerene, regio regular poly (3-alkylthiophene) such as regio regular poly (3-hexylthiophene), and π-conjugated macromolecule such as π-conjugated copolymer such as poly-9,9'-dialkylfluorene-cobithiophene.

[0040]

In the semiconductor device 1, a current (drain current) can flow between the source / drain electrode 7A and the source / drain electrode 7B through the the organic-semiconductor layer 8 by making the gate electrode into suitable potential with applying a suitable voltage (gate voltage) between gate electrode 2 and ground, and by applying a suitable voltage (drain voltage) between the source / drain electrode 7A and the source / drain electrode 7B. That is, this semiconductor device 1 functions as a field-effect transistor.

[0041]

Figure 2 is the illustrative perspective view showing the

configuration and arrangement of the source / drain electrodes 7A and 7B of the semiconductor device 1 of figure 1. In figure 2, the organic-semiconductor layer 8 is not shown.

The source / drain electrodes 7A and 7B include band-like section 7r mostly prolonged along the same straight-line, and protrusion 7p of almost triangular shape in plane view that are formed on the top of the band-like section 7r. Protrusion 7p of the source / drain electrode 7A has the tip configuration, and is tapering off toward the source / drain electrode 7B. Similarly, protrusion 7p of the source / drain electrode 7B has the tip configuration, and is tapering off toward the source / drain electrode 7A. That is, protrusion 7p of the source / drain electrode 7A and protrusion 7p of the source / drain electrode 7B are opposed to each other.

[0042]

In this embodiment, the head of protrusion 7p forms the ridgeline. Furthermore, protrusion 7p may be made into a tapered form also about the thickness direction, and head may substantially be a dot.

Spacing between protrusion 7p of the source / drain electrode 7A and protrusion 7p of the source / drain electrode 7B is preferably 1 micrometer or less.

With the such configuration of the source / drain electrodes 7A and 7B, if an voltage is applied between the source / drain electrodes 7A and 7B, electric field will concentrate near head 7e of protrusion 7p. Thus, since injection of a carrier takes place intensively near the head 7e by centralizing electric field near head 7e positively, a big drain current can flow through head 7e of protrusion 7p.

[0043]

Thus, a big drain current flows the limited area. Therefore, the source / drain electrodes 7A and 7B can be formed in a small area as compared with the conventional comb-like source / drain electrodes 72 and 73 (refer to figure 14). Therefore, the semiconductor device 1 can be miniaturized.

Moreover, the big ON/OFF ratio can be obtained even if spacing between protrusion 7p of the source / drain electrode 7A and protrusion 7p of the source / drain electrode 7B is narrow (for example, 1 micrometer or less).

[0044]

This semiconductor device 1 can be manufactured by the following

method, for example. First, gate oxide 3 is obtained by thermally oxidizing the surface of the gate electrode 2 made of silicon that is made to be conductive by the dope of impurities.

Then, the film made of titanium is formed on the whole surface of gate oxide 3 by spatter method, and the film made of platinum is formed on it by spatter method. And the film of titanium and the film platinum are shaped by ion milling, after performing electron beam exposure. Thereby, the source / drain electrode 7 is obtained.

[0045]

Next, the organic-semiconductor layer 8 is formed on the gate oxide 3 and the source / drain electrode 7 exposed according to the above step. In the case of a low-molecular organic semiconductor, the organic-semiconductor layer 8 can be formed by vacuum evaporation technique, or the application method such as cast, dip, and spin-coating with dissolving the low-molecule in solution medium. In the case of a macromolecule organic semiconductor, the organic-semiconductor layer 8 can be formed by the application method such as cast, dip, and spin-coating with dissolving the macromolecule in solution medium.

[0046]

Moreover, a layer may be formed using precursor of the low-molecular organic semiconductor or precursor of the macromolecule organic semiconductor by the above-mentioned method, and then thermal treatment may be done to form the organic-semiconductor layer 8. According to the above steps, the semiconductor device 1 shown in figure 1 is obtained.

Then, the semiconductor device 1 is heat-treated at suitable temperature as required. The heat-treatment removes unnecessary molecules (the molecule what does not contribute to conductivity, or what has the low contribution to conductivity) among the organic molecules contained in the organic-semiconductor layer 8, and arranges molecules that constitutes the organic-semiconductor layer 8 in the specific direction.

[0047]

When the organic-semiconductor layer 8 is made of chained oligomer (for example, thiophene-based oligomer), molecules can be made to arrange easily by heat treatment. Heat treatment temperature can be set to, for example, a temperature that is 5 C° to 10 C° lower than melting point (glass transition temperature) of the material which constitutes the organic-semiconductor layer 8. At such temperature, molecular motion becomes

active and chained oligomer is arranged for a short time.

The mobility of the organic-semiconductor layer 8 can be raised according to the above effect.

[0048]

Figure 3 is the illustrative top view showing the configuration and arrangement of source electrode 11S and drain electrode 11D that can be used instead of the source / drain electrodes 7A and 7B.

Source electrode 11S includes band-like section 11r same as band-like section 7r of the source / drain electrodes 7A and 7B, and protrusion 11p, same as protrusion 7p of the source / drain electrodes 7A and 7B, formed on the head of the band-like section 11r. Drain electrode 11D has band-like configuration mostly prolonged along the same straight-line with the band-like section 11r. The edge, by the side of source electrode 11S, of drain electrode 11D is flat part 11f which intersect perpendicularly in the direction in which band-like section 11r is prolonged.

[0049]

When a drain voltage is applied between source electrode 11S and drain electrode 11D, electric field concentrate near head 11e of source electrode 11S.

When the main carrier in the organic-semiconductor layer 8 is an electron, by grounding source electrode 11S and making drain electrode 11D into high potential to source electrode 11S, injection of a carrier takes place through head 11e of source electrode 11S, and a big drain current can flow. Moreover, when the main carrier in the organic-semiconductor layer 8 is a hole, by grounding drain electrode 11D and making source electrode 11S into high potential to drain electrode 11D, injection of a carrier takes place through head 11e of source electrode 11S, and a big drain current can flow.

[0050]

Figure 4 is the illustrative top view showing the structure of the semiconductor device of the second embodiment of this invention. This semiconductor device 15 is an organic thin film field-effect transistor. The semiconductor device 15 includes one pair of the source / drain electrodes 16A and 16B and one pair of other electrodes 17A and 17B on gate oxide 3 instead of the source / drain electrodes 7A and 7B of the semiconductor device 1 shown in figure 1. In figure 4, the organic-semiconductor layer 8 is not shown.

The source / drain electrodes 16A and 16B respectively include band-

like section 16r same as band-like section 7r of the source / drain electrodes 7A and 7B, and protrusion 16p, same as protrusion 7p of the source / drain electrodes 7A and 7B, formed on the head of the band-like section 16r.

Band-like section 16r of the source / drain electrode 16A and band-like section 16r of the source / drain electrode 16B are mostly arranged along the same straight-line. Protrusion 16p of the source / drain electrode 16A and protrusion 16p of the source / drain electrode 16B are opposed each other.

[0051]

Similarly, the electrodes 17A and 17B respectively include band-like section 17r same as band-like section 7r of the source / drain electrodes 7A and 7B, and protrusion 17p, same as protrusion 7p of the source / drain electrodes 7A and 7B, formed on the head of the band-like section 17r.

Band-like section 17r of the electrode 17A and band-like section 17r of the electrode 17B are mostly arranged along the same straight-line. Protrusion 17p of the electrode 17A and protrusion 17p of the electrode 17B are opposed each other.

[0052]

The opposite direction of the source / drain electrodes 16A and 16B, and the opposite direction of Electrodes 17A and 17B intersect almost at rights. Moreover, the gap between the source / drain electrode 16A and the source / drain electrode 16B and the gap between electrode 17A and electrode 17B overlaps. That is, one pair of the source / drain electrodes 16A and 16B, and one pair of electrodes 17A and 17B are opposed to each other across the common area of the organic-semiconductor layer 8.

The electrode pad 18 is connected to the side, which is opposite to the protrusion 16p and 17p, of the band-like sections 16r and 17r.

[0053]

The semiconductor device 15 can apply a drain voltage between protrusion 16p of the source / drain electrode 16A and protrusion 16p of the source / drain electrode 16B through the electrode pad 18 connected to band-like section 16r. In this case, electric field concentrates near the head 16e of protrusion 16p. For this reason, a big drain current can flow through head 16e of protrusion 16p. Furthermore, when a drain current flows, a magnetic field is applied to the semiconductor device 15 in the direction which intersects perpendicularly to the opposite direction of the source / drain electrodes 16A and 16B and to the opposite direction of

electrodes 17A and 17B (it is perpendicularly to the sheet of figure 4), and the potential difference between electrodes 17A and 17B is measured through the electrode pad 18 connected to band-like section 17r. Thereby, the carrier mobility of the organic-semiconductor layer can be measured by hall effect measurement.

[0054]

Figure 5 is an illustrative top view showing the structures of the semiconductor devices of the third embodiment and its modification of this invention. These semiconductor devices 20A-20C are organic thin film field-effect transistors. The semiconductor devices include, on the gate oxide film 3, one pair of source / drain electrodes 21A and 21B (figure 5 (a)), one pair of source 23S and drain electrode 23D (figure 5 (b)), or one pair of source / drain electrodes 25A and 25B (figure 5 (c)) instead of the source / drain electrodes 7A and 7B of the semiconductor device 1 shown in figure 1. In figure 5, organic-semiconductor layer 8 is not shown.

[0055]

With reference to figure 5 (a), the source / drain electrodes 21A and 21B of semiconductor device 20A respectively include band-like sections 21r that are disposed almost parallel to each other. From band-like section 21r of the source / drain electrode 21A, two or more protrusion 21p protrudes toward the source / the drain electrode 21B. In plane view, protrusion 21p of the source / drain electrode 21A has the configuration of almost triangular shape, and is tapering off toward the source / drain electrode 21B.

[0056]

Similarly, from band-like section 21r of the source / drain electrode 21B, protrusions 21p of the same number as protrusions 21p of the source / drain electrode 21A protrude toward the source / drain electrode 21A. In plane view, protrusion 21p of the source / drain electrode 21B has the configuration of almost triangular shape, and is tapering off toward the source / drain electrode 21A.

Protrusion 21p of the source / drain electrode 21A and protrusion 21p of the source / drain electrode 21B are opposed to each other. Thereby, spacing between the source / drain electrode 21A and the source / drain electrode 21B is narrow in two or more parts in which protrusions 21p exist. Thereby, when a voltage is applied between the source / drain electrode 21A and the source / drain electrode 21B, electric field concentrates near heads

21e of each protrusions 21p. Therefore, a big drain current can flow through such heads 21e. Since a plurality of heads 21e exist, a drain current can be enlarged as total.

[0057]

At the time of current-flow, between the source / drain electrodes 21A and 21B, a plurality of electric-field concentrating regions exist discretely with almost constant spacing.

With reference to figure 5 (b), source electrode 23S of semiconductor device 20B has the same configuration as the source / drain electrode 21A, and is equipped with band-like section 21r same as band-like section 23r, and protrusions 23p same as protrusions 21p. Drain electrode 23D has a band-like configuration, and is opposed to band-like section 21r so as to be parallel to band-like section 21r. The side (source electrode 23S side) of drain electrode 23D is flat part 23s that is almost parallel to the direction where band-like section 23r is prolonged.

[0058]

Source electrode 23S can achieve same effect as source electrode 11S, and drain electrode 23D can achieve same effect as drain electrode 11D (refer to figure 3). Therefore, the semiconductor device 20B can achieve same effect as the semiconductor device having source electrode 11S and drain electrode 11D shown in figure 3. In this case, since a big drain current can flow through heads 23e of protrusions 23p, the drain current between source electrode 23S and drain electrode 23D can be enlarged as total compared with the semiconductor device having source electrode 11S and drain electrode 11D. And the big ON/OFF ratio can be maintained even if the gap between heads 23e that are opposed to each other is 1 micrometer or less.

[0059]

At the time of current-flow, between the source electrode 23S and drain electrode 23S, a plurality of electric-field concentrating regions exist discretely with almost constant spacing.

With reference to figure 5 (c), the source / drain electrodes 25A and 25B of semiconductor device 20C respectively include band-like sections 25r that are opposed to each other. From band-like section 25r of the source / drain electrode 25A, one protrusion 25p protrudes toward a source / drain electrode 25B. In plane view, protrusion 25p has the configuration of almost triangular shape, and is tapering off toward the source / drain

electrode 25B.

[0060]

Similarly, from band-like section 21r of the source / drain electrode 21B, one protrusion 21p protrudes toward a source / drain electrode 21A. In plane view, protrusion 21p has the configuration of almost triangular shape, and is tapering off toward the source / drain electrode 21A.

The parts, that is opposed to each other, of band-like section 25r serves as flat parts 25f except the part in which protrusion 25A is formed. Protrusion 25p of the source / drain electrode 25A and flat part 25f of the source / drain electrode 25B are opposed to each other, and protrusion 25p of the source / drain electrode 25B and flat part 25f of the source / drain electrode 25A are opposed to each other.

[0061]

In the semiconductor device 20C, a big drain current can flow through head 25e of protrusion 25p of the source / drain electrode 25A or head 25e of protrusion 25p of the source / drain electrode 25B, depending on the kinds of main carrier in the organic-semiconductor layer 8 and the direction of the voltage applied between the source / drain electrodes 25A and 25B.

Figure 6 is an illustrative top view showing the structure of the semiconductor device of the forth embodiment of this invention. The semiconductor device 27 is an organic thin film field-effect transistor, and is equipped with one pair of the source / drain electrodes 28A and 28B on gate oxide 3 instead of the source / drain electrodes 7A and 7B of the semiconductor device 1 shown in figure 1. In figure 6, the organic-semiconductor layer 8 is not shown.

[0062]

The source / drain electrodes 28A and 28B include respectively band-like sections 28r that are opposed, in parallel, to each other. From band-like sections 28r of the source / drain electrodes 28A and 28B, a plurality of protrusions 28p protrude toward a source / drain electrode 28B and 28A. Protrusion 28p is tapering off toward the source / drain electrode 28B and 28A. Head 28e of protrusion 28p forms a convex curvature.

[0063]

Protrusion 28p of the source / drain electrode 28A and protrusion 28p of the source / drain electrode 28B are opposed to each other. Thereby, spacing between the source / drain electrode 28A and the source / drain

electrode 28B is narrow in two or more parts in which protrusions 28p exist. Therefore, even if the head 28e of protrusion 28 is roundish, electric field can be centralized near head 28e of each protrusion 28p, and a big drain current can flow through head 28e.

[0064]

Figure 7 is the illustrative top view showing the structure of the semiconductor device of the fifth embodiment of this invention. The semiconductor device 29 is an organic thin film field-effect transistor, and is equipped with one pair of the source / drain electrodes 30A and 30B on gate oxide 3 instead of the source / drain electrodes 7A and 7B of the semiconductor device 1 shown in figure 1. In figure 7, the organic-semiconductor layer 8 is not shown.

The source / drain electrodes 30A and 30B respectively include band-like sections 30r that are opposed, in parallel, to each other. From band-like sections 30r of the source / drain electrodes 30A and 30B, a plurality of protrusions 30p protrude toward a source / drain electrodes 30B and 30A. Protrusion 30p has the head configuration of almost fixed width, and does not taper off toward the source / drain electrode 30B and 30A.

[0065]

Protrusion 30p of the source / drain electrode 30A and protrusion 30p of the source / drain electrode 30B are opposed to each other. Thereby, spacing between the source / drain electrode 30A and the source / drain electrode 30B is narrower at parts in which protrusions 30p exist than other parts. Therefore, even if protrusions 30p which is not tapering off is formed, electric field can be centralized near head 30e of each protrusion 30p, and a big drain current can flow through head 30e. And a big ON/OFF ratio can be maintained even if the gaps between heads 30e that are opposed to each other is 1 micrometer or less.

[0066]

Figure 8 is an illustrative top view showing the structure of the semiconductor device of the 6th embodiment of this invention. The semiconductor device 31 is an organic thin film field-effect transistor, and is equipped with one pair of the source / drain electrodes 32A and 32B on gate oxide 3 instead of the source / drain electrodes 7A and 7B of the semiconductor device 1 shown in figure 1. In figure 8, the organic-semiconductor layer 8 is not shown.

The source / drain electrodes 32A and 32B have comb-like shape. In

the opposite section of the source / drain electrodes 32A and 32B, many minute protrusions 32p protrude at the periphery section of the source / drain electrodes 32A and 32B. Protrusion 32p has the tapering configuration. Protrusion 32p of the source / drain electrode 32A and protrusion 32p of the source / drain electrode 32B are opposed to each other.

[0067]

By such configuration, spacing between the source / drain electrode 32A and the source / drain electrode 32B is narrow at parts in which protrusions 32p exist. Therefore, electric field can be centralized near the head of protrusion 32p, a big drain current can flow compared with the conventional comb-like source / drain electrodes 72 and 73 (refer to figure 14). And a big ON/OFF ratio can be maintained even if the gap between protrusions 32p that are opposed to each other is 1 micrometer or less.

[0068]

Figure 9(a) is an illustrative top view of the semiconductor device (organic thin film field-effect transistor) of the 7th embodiment of this invention. Figure 9(b) is an illustrative sectional view of the semiconductor device of its modification. Figures 9(c) and (d) are illustrative top views of the semiconductor device of another modification. In figures 9(a), (c), and (d), the organic-semiconductor layer 8 is not shown.

With reference to figure 9(a), in the semiconductor device 35A, a carbon nanotube 36 is connected to head 7e of protrusion 7p of the source / drain electrodes 7A and 7B of the semiconductor device 1 shown in figure 1. The carbon nanotube 36 connected to the source / drain electrodes 7A and 7B is turned to the source / drain electrodes 7B and 7A.

[0069]

Since a diameter of the carbon nanotube 36 is in the order of nanometer (nm), electric field can be centralized near the head of the carbon nanotube 36 effectively. Therefore, a big ON/OFF ratio can be obtained.

The carbon nanotube 36 may be combined with parts other than head 7e of protrusion 7p, as shown in a two-dot chain line of figure 9(a). Furthermore, the carbon nanotube 36 may be combined with the whole surface in contact with the organic-semiconductor layer 8 of the source / drain electrodes 7A and 7B as semiconductor device 35B shown in figure 9(b).

[0070]

With reference to figure 9(c), the semiconductor device 35C is equipped with one pair of the source / drain electrodes 37A and 37B on gate oxide 3 instead of the source / drain electrodes 7A and 7B of the semiconductor device 1 shown in figure 1. The source / drain electrodes 37A and 37B respectively include band-like sections 37r that are opposed, in parallel, to each other. From band-like section 37r of the source / drain electrodes 37A and 37B, a plurality of carbon nanotubes 36 protrude toward a source / drain electrode 37B and 37A. Also in this case, electric field can be centralized at the head of a carbon nanotube 36, and a big ON/OFF ratio can be obtained.

[0071]

The carbon nanotube 36 connected to the source / drain electrode 37A and the carbon nanotube 36 connected to the source / drain electrode 37B do not need to be be opposed to each other with strict alignment. In this case, a bigger drain current flows in the combination with the shortest distance among combinations between the head of the carbon nanotube 36 connected to the source / drain electrode 37A and the head of the carbon nanotube 36 connected to the source / drain electrode 37B

[0072]

With reference to figure 9(d), the semiconductor device 35D is equipped with one pair of source electrode 38S and drain electrode 38D on gate oxide 3 instead of the source / drain electrodes 7A and 7B of the semiconductor device 1 shown in figure 1.

Source electrode 38S has the same configuration as the source / drain electrode 37A (refer to figure 9(c)), and contains band-like section 38r same as band-like section 38r and carbon nanotubes 36 connected to band-like section 37r. Drain electrode 38D has the band-like configuration, and are opposed in parallel to band-like section 38r. The side (source electrode 38S side) of drain electrode 38D is flat parts 38f almost parallel to the direction where band-like section 38r is prolonged. The carbon nanotube 36 protrudes toward drain electrode 38D.

[0073]

Source electrode 38S can achieve the same effect as source electrode 11S, and drain electrode 38D can achieve the same effect as drain electrode 11D (refer to figure 3). Therefore, the semiconductor device 35D can achieve the same effect as the semiconductor device having source electrode 11S and drain electrode 11D shown in figure 3. In this case, since a big

drain current can flow through the head of carbon nanotubes 36, a drain current can be enlarged as total compared with the semiconductor device having source electrode 11S and drain electrode 11D. And a big ON/OFF ratio can be obtained.

[0074]

The titania nanotube may be formed in the source / drain electrodes 7A, 7B, 37A, and 37B and source electrode 38S, instead of a carbon nanotube 36, or, with the carbon nanotube 36.

Furthermore, the nanowire may be formed instead of nanotubes such as a carbon nanotube 36 and a titania nanotube, or, with the nanotube. The nanowire can be made of a conductive material used for electrode materials, such as gold, platinum, and silver.

[0075]

A carbon nanotube 36 can be connected to the source / drain electrodes 7A, 7B, 37A, and 37B, and source electrode 38S by an electrophoresis method.

Figure 10 is an illustrative sectional view showing the structure of the semiconductor device concerning the 8th embodiment of this invention.

The semiconductor device 40 is an organic thin film field-effect transistor. Gate insulating film 43 made of silicon oxide, the organic-semiconductor layer 44, and one pair of the source / drain electrodes 45A and 45B are formed in this order on the gate electrode 42 made of silicon that is made to be conductive by the dope of impurities.

[0076]

Gate insulating film 43 is formed on the whole surface of gate electrode 42, and the organic-semiconductor layer 44 is formed on the whole surface of gate insulating film 43. The source / drain electrode 45A and the source / drain electrode 45B are opposed to each other across the gap.

The source / drain electrodes 45A and 45B are made of the same conductive material as the source / drain electrodes 7A and 7B. The organic-semiconductor layer 44 can be made of the same organic-semiconductor material as the organic-semiconductor layer 8.

[0077]

In the semiconductor device 40, a current (drain current) can flow between the source / drain electrode 45A and the source / drain electrode 45B through the organic-semiconductor layer 44 by making the gate electrode 42 into suitable potential with applying a suitable voltage (gate

voltage) between the gate electrode 42 and the ground, and by applying a suitable voltage (drain voltage) between the source / drain electrode 45A and the source / drain electrode 45B. That is, the semiconductor device 40 functions as a field-effect transistor.

[0078]

The planar configuration of the source / drain electrodes 45A and 45B may be the same as the planar configuration of the source / drain electrodes 7A, 7B, 21A, 21B, 25A, 25B, 28A, 28B, 30A, 30B, 32A, 32B, 37A, and 37B, and may be these electrodes to which carbon nanotubes 36 connected. Moreover, the source electrode and drain electrode which have the planar configuration same as the source electrodes 11S, 23S, and 38S and the drain electrodes 11D, 23D, and 38D may be formed instead of the source / drain electrodes 45A and 45B.

In any case, a big drain current can flow by electric-field concentration, and a good ON/OFF ratio is obtained.

[0079]

Furthermore, two pairs of electrodes may be formed by the rectangular arrangement same as the electrodes 16A, 16B, 17A, and 17B shown in figure 4 instead of the source / drain electrodes 45A and 45B. Such a semiconductor device can achieve the same effect as the semiconductor device 15 shown in figure 4.

Figure 11 is the illustrative top view showing the structure of the semiconductor device concerning the 9th embodiment of this invention. This semiconductor device 50 contains, on the organic-semiconductor layer 51, one pair of the source / drain electrodes 52A and 52B that are opposed to each other and the gate electrode 53 arranged in the side of the opposite section of the source / drain electrodes 52A and 52B.

[0080]

The source / drain electrodes 52A and 52B include respectively band-like section 52r mostly prolonged along the same straight-line, and protrusion 52p of almost triangular shape in plane view. Protrusion 52p of the source / drain electrodes 52A and 52B has the head configuration, and is tapering off toward the source / drain electrodes 52B and 52A. That is, protrusion 52p of the source / drain electrode 52A and protrusion 52p of the source / drain electrode 52B are opposed to each other. The electrode pad 54 is connected the side (opposite side to the protrusion 52p) of band-like section 52r.

[0081]

The gate electrode 53 is mostly prolonged in parallel in the array direction of the source / drain electrodes 52A and 52B. Gate insulating film 55 is formed on the gate electrode 53. Gate insulating film 55 is formed so that it laps with the gate electrode 53 thoroughly in plane view. Therefore, the gate electrode 53 is opposed to the organic-semiconductor layer 51 between the source / drain electrode 52A and 52B across the gate insulating film 55.

In the semiconductor device 50 a current (drain current) can flow between the source / drain electrode 52A and the source / drain electrode 52B through the organic-semiconductor layer 51 by making the gate electrode 53 into suitable potential with applying a suitable voltage (gate voltage) between the gate electrode 53 and the ground, and by applying a suitable voltage (drain voltage) between the source / drain electrode 52A and the source / drain electrode 52B. That is, the semiconductor device 50 functions as a field-effect transistor.

[0082]

In this case, since electric field concentrate near the head 52e of protrusion 52p, a big drain current can be flow through the head 52e, and a good ON/OFF ratio can be obtained.

Although explanation of embodiments of this invention is as above, this invention can be carried out with other embodiments. For example, one source / drain electrode or a source electrode includes more than two kinds of protrusions 7p, 28p and 30p selecting from protrusion 7p having a head configuration shown in figure 2, protrusion 28p tapering off and not having a head configuration shown in figure 6, and protrusion 30p not tapering off and having almost fixed width.

[0083]

Moreover, in the source / drain electrodes 32A and 32B shown in figure 8, the protrusion may be formed with the carbon nanotube and/or the titania nanotube instead of protrusion 32p.

In addition, it is possible to perform various modifications in the range of the matter indicated by the claim.

[0084]

[Example]

The semiconductor device 15 which has the source / drain electrodes 16A and 16B of the head configuration shown in figure 4, and the

semiconductor device 70 which has the comb-like source / drain electrodes 72 and 73 shown in figure 14 were produced, and each current-voltage characteristic was measured.

The manufacture method of semiconductor devices 15 and 70 is as follows. The gate electrode 2 was made of high doped silicon (Si). The gate oxide films 3 and 71 made of silicon oxide were formed by thermally oxidizing the gate electrode 2 to a depth of about 100nm. The titanium thin film was formed on the whole surface of the gate oxide films 3 and 71 by spatter. And the platinum thin film was further formed on the whole surface of the titanium thin film.

[0085]

Then, the titanium thin film and the platinum thin film were shaped by electron beam exposure and ion milling. Thus, the source / drain electrodes 16A and 16B and electrodes 17A and 17B of a head configuration shown in figure 4 were formed in a semiconductor device 15, and the comb-like source / drain electrodes 72 and 73 shown in figure 14 were formed in the semiconductor device 70. Concerning the semi-conductor device 15, spacing between protrusions 16p opposed to each other, and spacing between protrusions 17p opposed to each other were set to about 1 micrometer. Concerning the semiconductor device 70, spacing between the source / drain electrode 72 and the source / drain electrode 73 was set to 25 micrometers or 1 micrometer.

[0086]

Next, organic-semiconductor layer 8 made of a phenyl-terminated thiophene trimer (P3T) was formed by vacuum deposition on whole surface of the side (the side in which the source / drain electrodes 16A, 16B, 72, and 73 were formed) of gate oxide film 3 and 71 so that the source / drain electrodes 16A, 16B, 72, and 73 would be covered. Vacuum deposition was performed on conditions with a degree of vacuum of 10^{-4} Pa, an evaporation rate of 0.5 nm/min, and a substrate temperature of 80 °C. Thus, the organic-semiconductor layer 8 in which the molecule shaft of a phenyl-terminated thiophene trimer molecule arranged almost at right angles to gate oxide 3 and 71, and carried out stratified growth was obtained.

[0087]

Figure 12(a) - (c) is property figure showing the relation between the drain voltage and a drain current for every gate voltage. Figure 12(a) shows a measurement result of the semiconductor device 15 (example).

Figure 12(b) shows a measurement result of the semiconductor device 70 (hereinafter called "the comparison sample 1") having spacing of 25 micrometers between the source / drain electrodes 72 and 73. Figure 12 (c) shows a measurement result of the semiconductor device 70 (hereinafter called "the comparison sample 2") having spacing of 1 micrometer between the source / drain electrodes 72 and 73. Gate voltage (voltage between the gate electrode 2 and the ground) was set to 0V, -5V, -10V, -15V, and -20V.

[0088]

Concerning the semiconductor device 15 and the comparison sample 1, when gate voltage is applied and a drain voltage is close to 0, a drain current becomes large with reduction of a drain voltage, and when a drain voltage is beyond about -10 to -30V, a drain current is not based on a drain voltage and is almost fixed (figure 12(a), (b)).

On the other hand, concerning the comparison sample 2, a drain current is not based on gate voltage and is increasing in monotone with reduction of a drain voltage.

[0089]

That is, when the comb-like source / drain electrodes 72 and 73 are used and spacing between the source / drain electrodes 72 and 73 is as large as about 25 micrometers, there is little change of the drain current over a drain voltage, but when spacing between the source / drain electrode 72 and 73 is as small as about 1 micrometer, change of the drain current over a drain voltage is large. On the other hand, when the source / drain electrodes 16A and 16B having a tip configuration are used and spacing between the source / drain electrodes 16A and 16B is as small as about 1 micrometer, there is little change of the drain current over a drain voltage.

[0090]

Figure 13 is property figure showing the measurement result of the relation between measurement temperature and the carrier mobility of the organic-semiconductor layer 8.

In the semiconductor device 15, mobility becomes high according to that the measurement temperature becomes high. Especially, when the measurement temperature is about 325-350K, mobility is rising rapidly with the measurement temperature. Mobility is decreasing because of destruction of the element accompanying melting of the organic-semiconductor layer 8 in when the measurement temperature is about 350K or more.

[0091]

The above thing shows that a semiconductor device 15 can make mobility high by heat treatment. It is considered that the mobility was improved because unnecessary molecules (the molecules which do not contribute to conductivity, or which have the small contribution to conductivity) were removed by heat treatment, and the rearrangement of a molecule (crystal) happened. It is considered to be able to improve drastically by performing heat treatment under the melting temperature of the organic-semiconductor layer since the molecular arrangement maintains even after the device is cooled to the room temperature.

[Brief Description of the Drawings]

[Figure 1] Figure 1 is an illustrative sectional view showing the structure of the semiconductor device concerning the first embodiment of this invention.

[Figure 2] Figure 2 is an illustrative perspective view showing the configuration and arrangement of the source / drain electrode of the semiconductor device of figure 1.

[Figure 3] Figure 3 is an illustrative top view showing the configuration and arrangement of the source electrode which can be used instead of the source / drain electrode shown in figure 1.

[Figure 4] Figure 4 is an illustrative top view showing the structure of the semiconductor device concerning the second embodiment of this invention.

[Figure 5] Figure 5 is an illustrative top view showing the structures of the semiconductor device concerning third embodiment of this invention, and its modification.

[Figure 6] Figure 6 is an illustrative top view showing the structure of the semiconductor device concerning the fourth embodiment of this invention.

[Figure 7] Figure 7 is an illustrative top view showing the structure of the semiconductor device concerning the fifth embodiment of this invention.

[Figure 8] Figure 8 is an illustrative top view showing the structure of the semiconductor device concerning the 6th embodiment of this invention.

[Figure 9] Figure 9 is an illustrative top view and sectional view of a semiconductor device concerning the semiconductor device concerning the 7th embodiment of this invention, and its modification.

[Figure 10] Figure 10 is an illustrative sectional view showing the structure of the semiconductor device concerning the 8th embodiment of this invention.

[Figure 11] Figure 11 is an illustrative top view showing the structure of the semiconductor device concerning the 9th embodiment of this invention.

[Figure 12] Figure 12 is a property figure showing the relation between the drain voltage and a drain current for every gate voltage.

[Figure 13] Figure 13 is a property figure showing the relation between measurement temperature and the mobility of an organic-semiconductor layer.

[Figure 14] Figure 14 is an illustrative top view showing the configuration of the source / drain electrode of the conventional organic thin film field-effect transistor.

[Description of Notations]

1, 15, 20A-20C, 27, 29, 31, 35A-35D, 40, 50: Semiconductor device
2, 42, 53: Gate electrode
3, 43: Gate oxide
55: Gate Insulating Film
7A, 7B, 21A, 21B, 25A, 25B, 28A, 28B, 30A, 30B, 32A, 32B, 37A, 37B, 45A, 45B, 52A, and 52B: Source drain electrode
7p, 11p, 16p, 21p, 23p, 25p, 28p, 30p, 32p, 52p: Protrusion
7e, 11e, 16e, 21e, 23e, 25e, 52e: Head
8, 44, 51: Organic-semiconductor layer
11S, 23S, 38S: Source electrode
11D, 23D, 38D: Drain electrode
17A, 17B: Electrode
36: Carbon Nanotube

[Abstract]

[Problem(s)] To offer a semiconductor device containing the organic semiconductor which can be miniaturized.

[Means for solving the problem] The semiconductor device 1 includes gate oxide film 3, one pair of the source / drain electrodes 7A and 7B, and organic-semiconductor layer 8 are formed in this order on the gate electrode. The source / drain electrodes 7A and 7B respectively include band-like section 7r mostly prolonged along the same straight-line, and protrusion 7p of almost triangular shape in plane view that are formed on the top of the band-like section 7r. Protrusion 7p of the source / drain electrodes 7A and 7B have the tip configuration, and are tapering off toward the source / drain electrode 7B and 7A. Spacing between protrusion 7p of the source / drain electrode 7A and protrusion 7p of the source / drain electrode 7B is preferably 1 micrometer or less.

[Selected figure] Figure 2

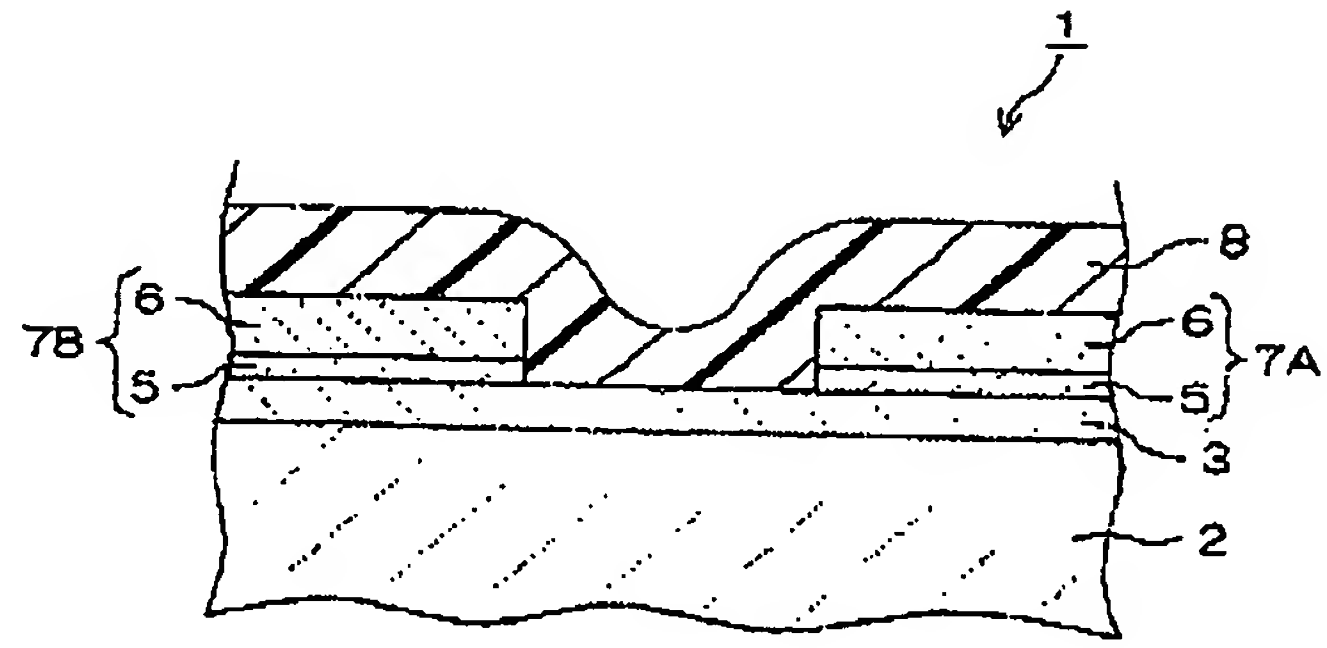


Fig. 1

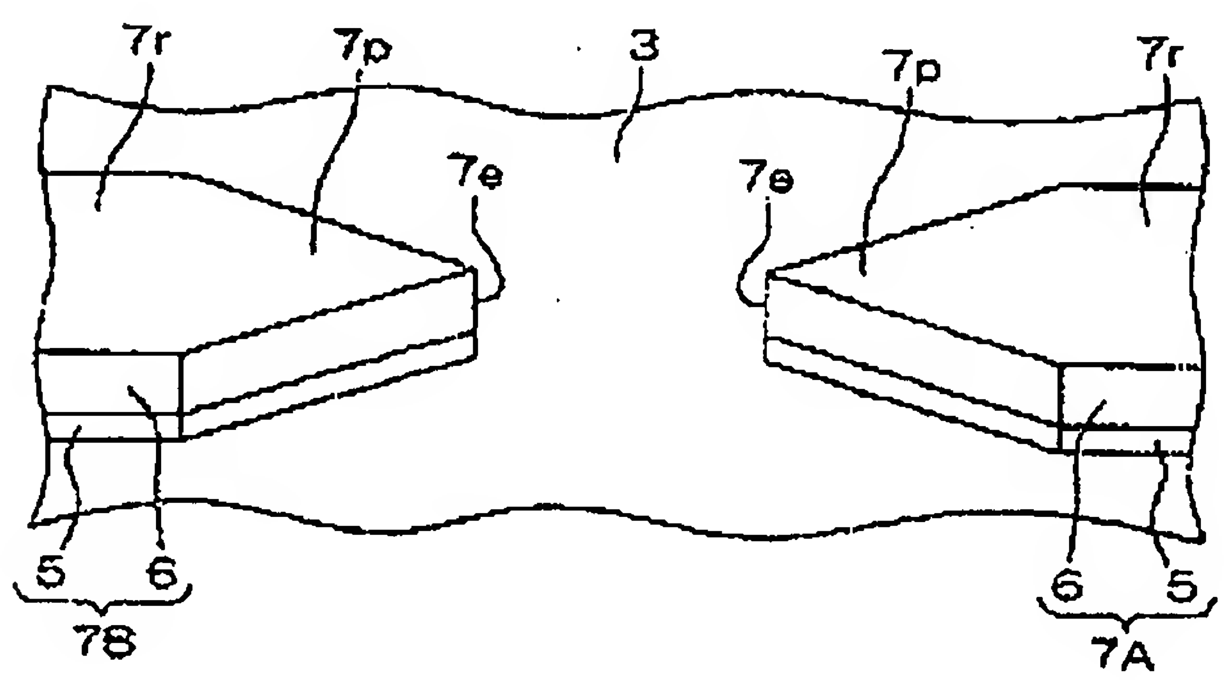


Fig. 2

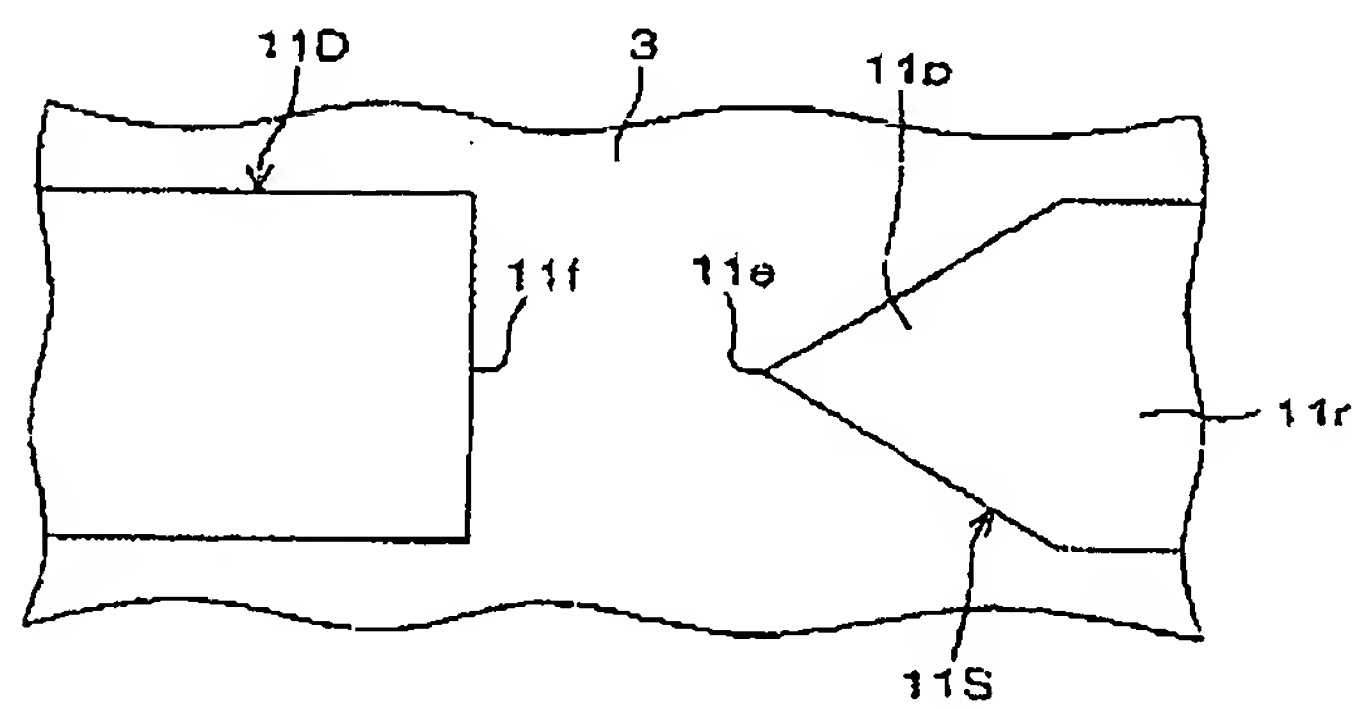


Fig. 3

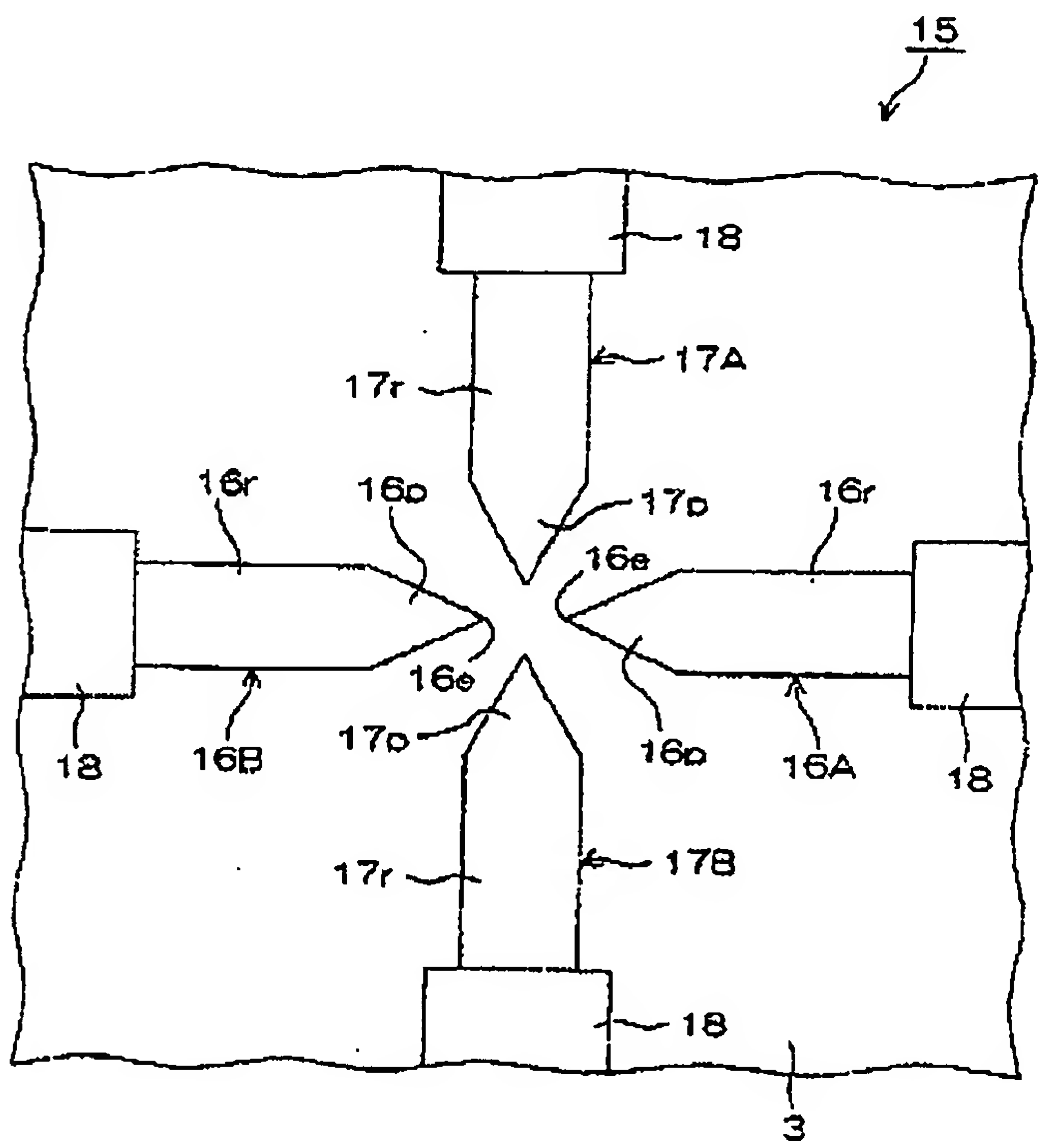

15
18
17A
17r
16r
16p
17p
16r
16e
16e
17p
16B
18
16p
16A
18
17r
17B
18
3

Fig. 4

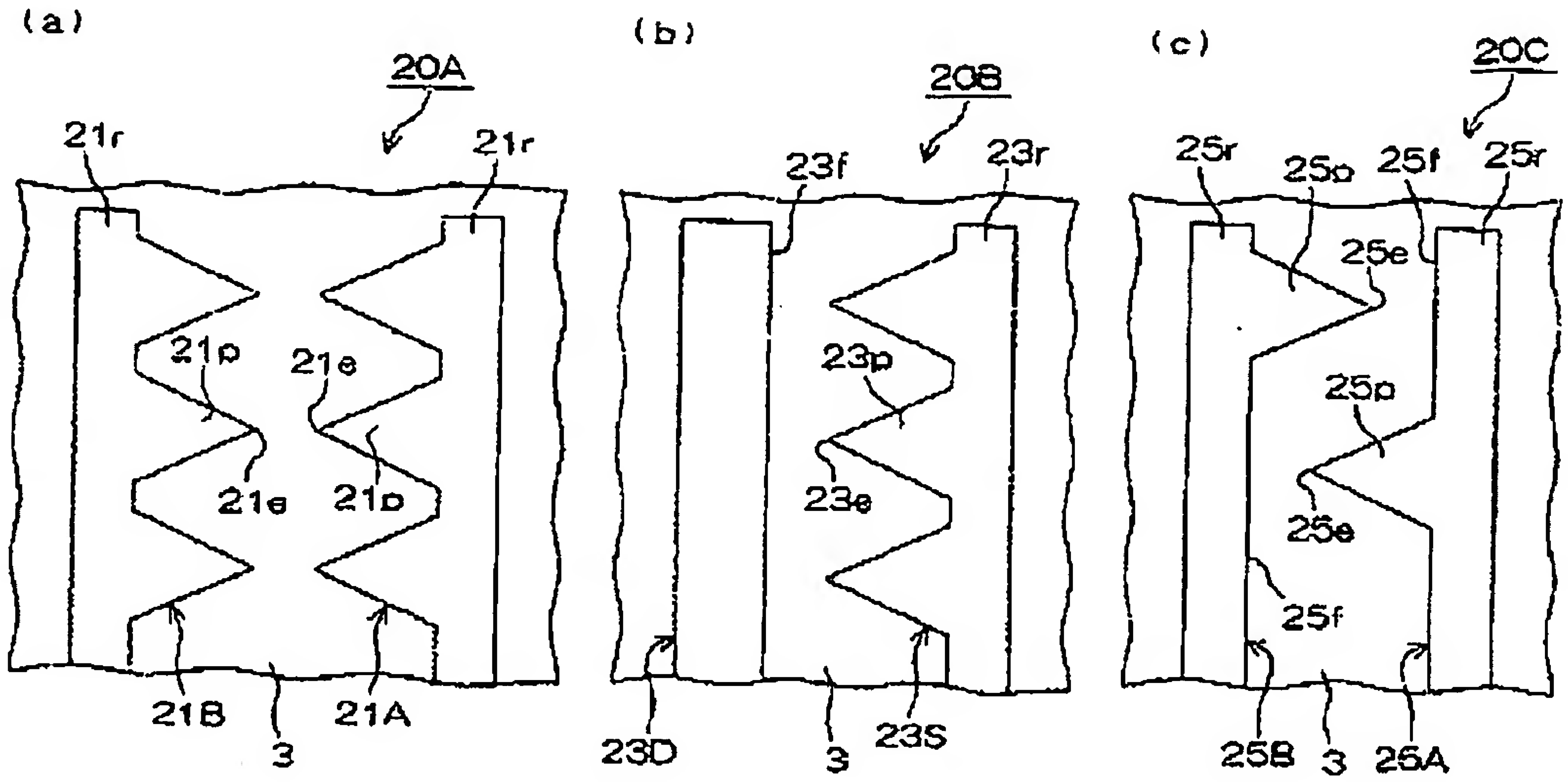


Fig. 5

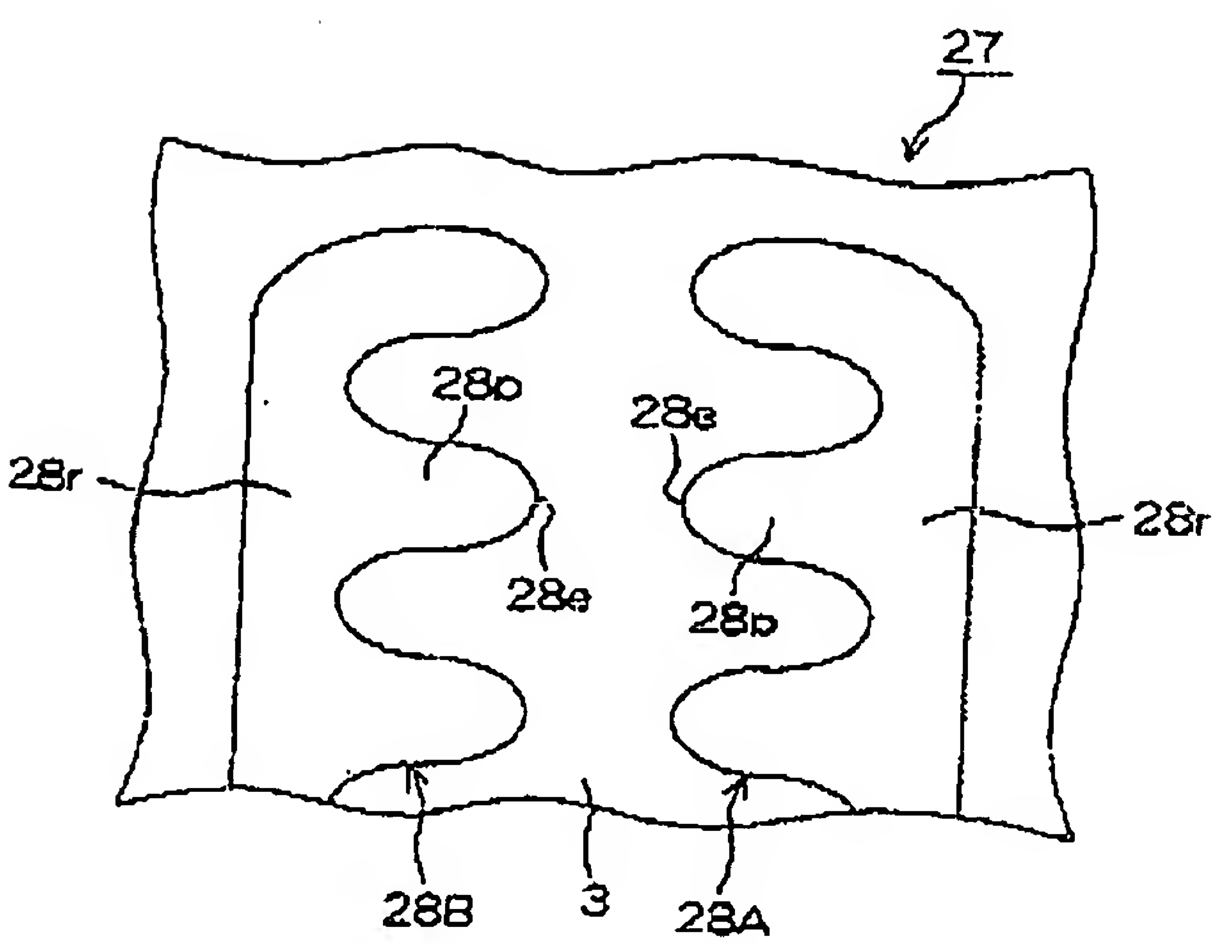


Fig. 6

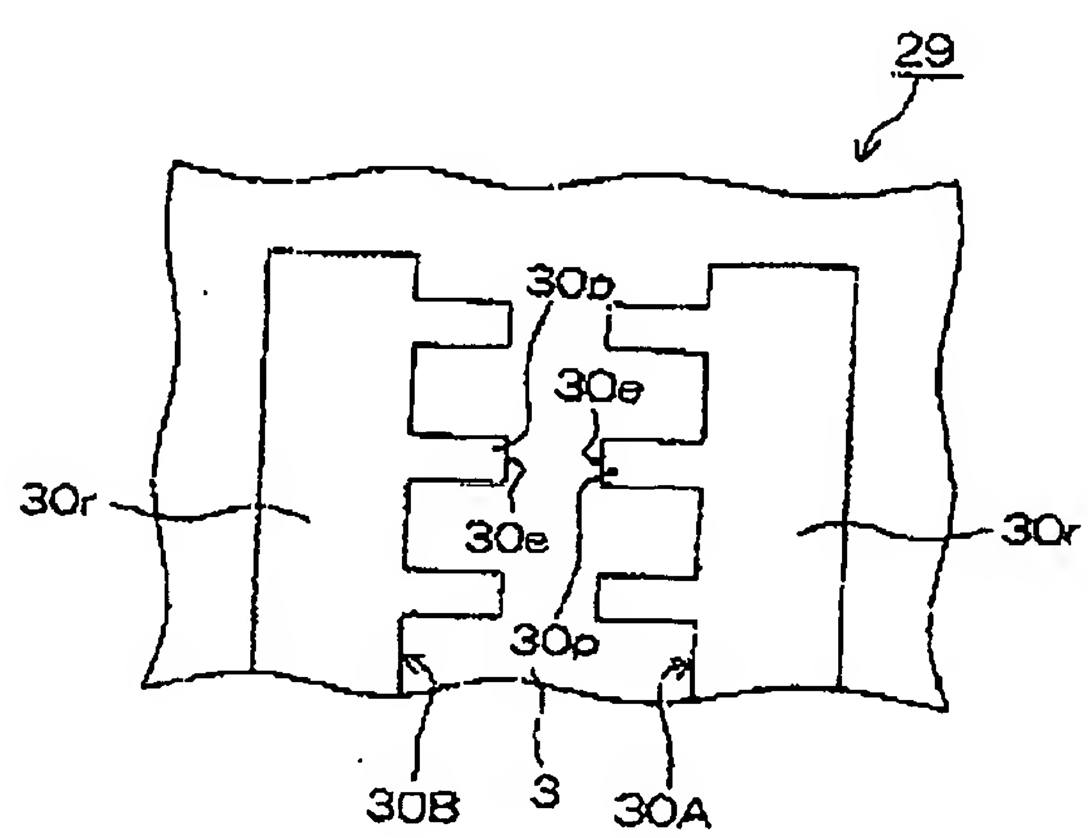
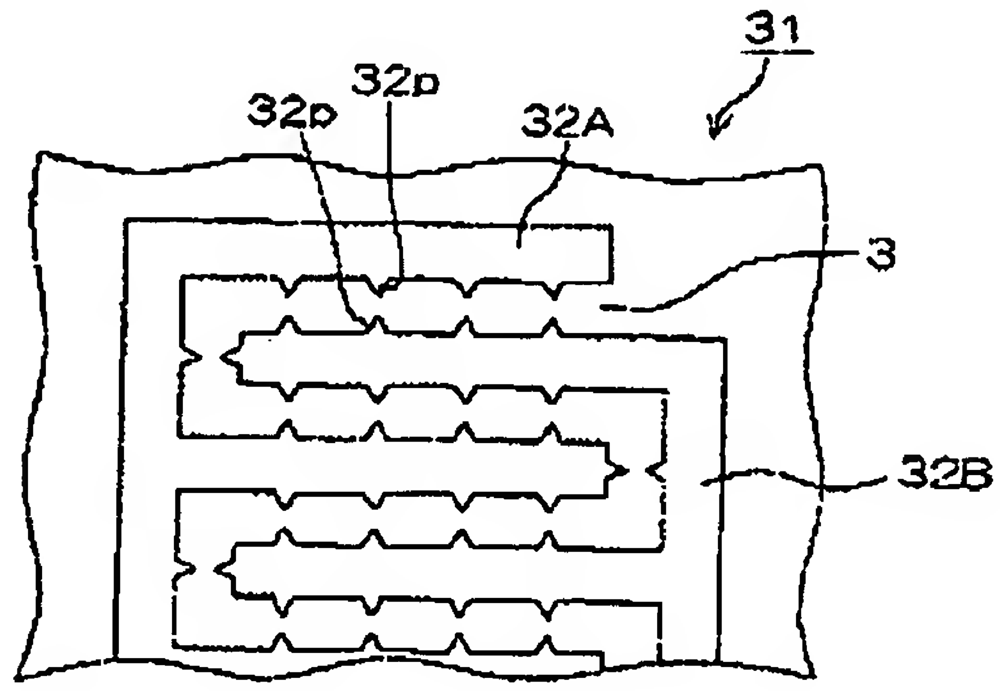
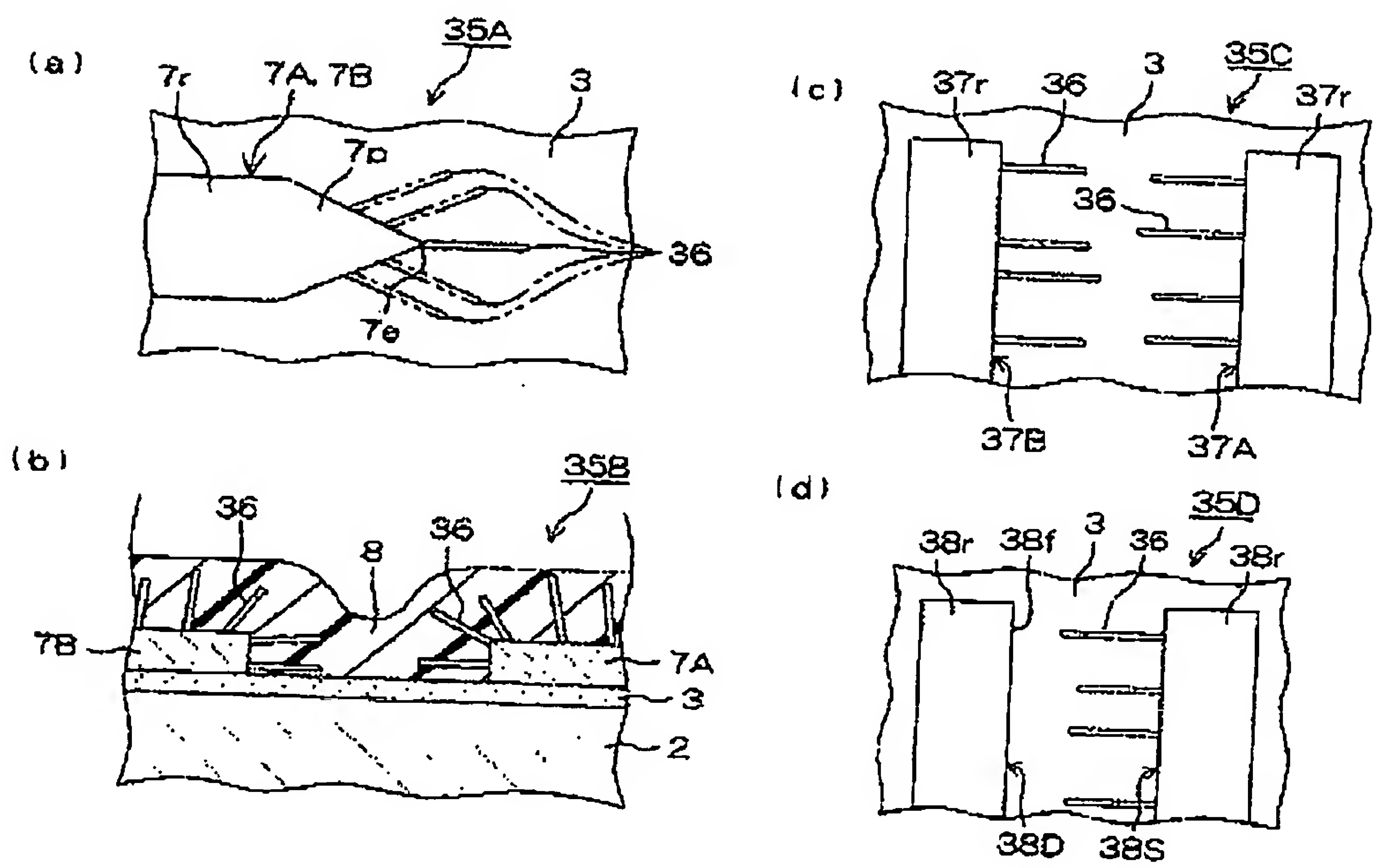


Fig. 7



31
32p
32p
32A
3
32B

Fig. 8



(a)
35A
7r
7A, 7B
3
7p
36
7e
(b)
35B
36
36
8
7B
7A
3
2
(c)
35C
37r
36
3
37r
36
37B
37A
(d)
35D
38r
38f
3
36
38r
38D
38S

Fig. 9

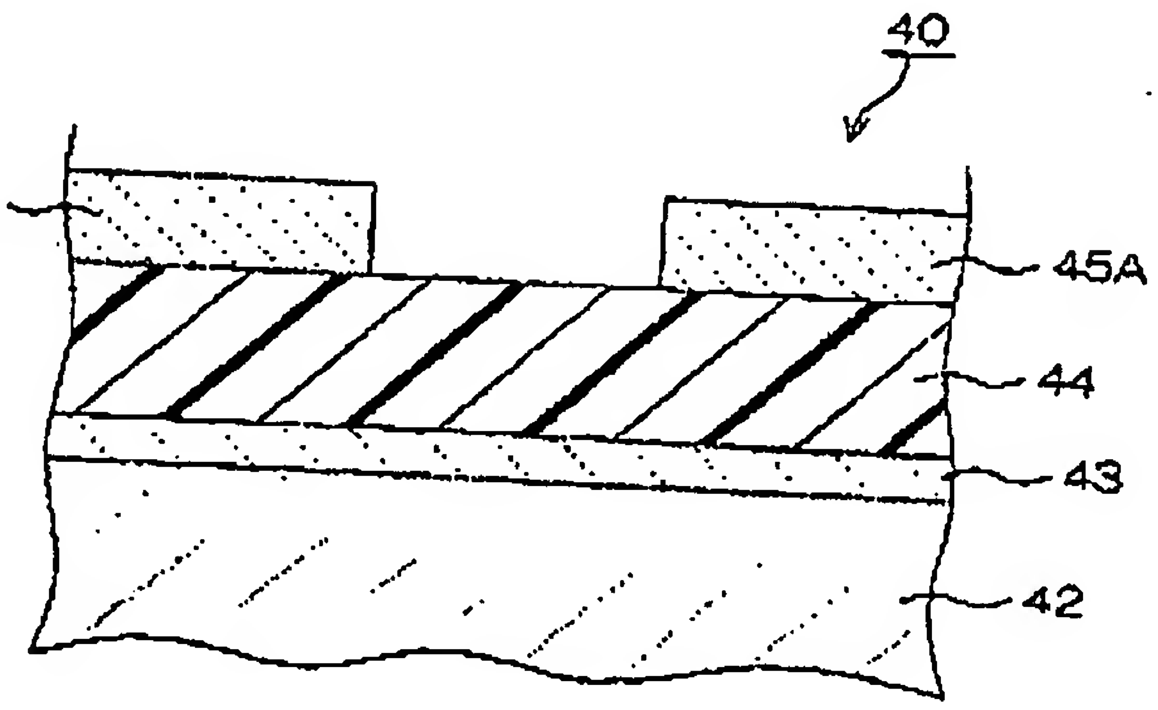

40
45B
45A
44
43
42

Fig. 10

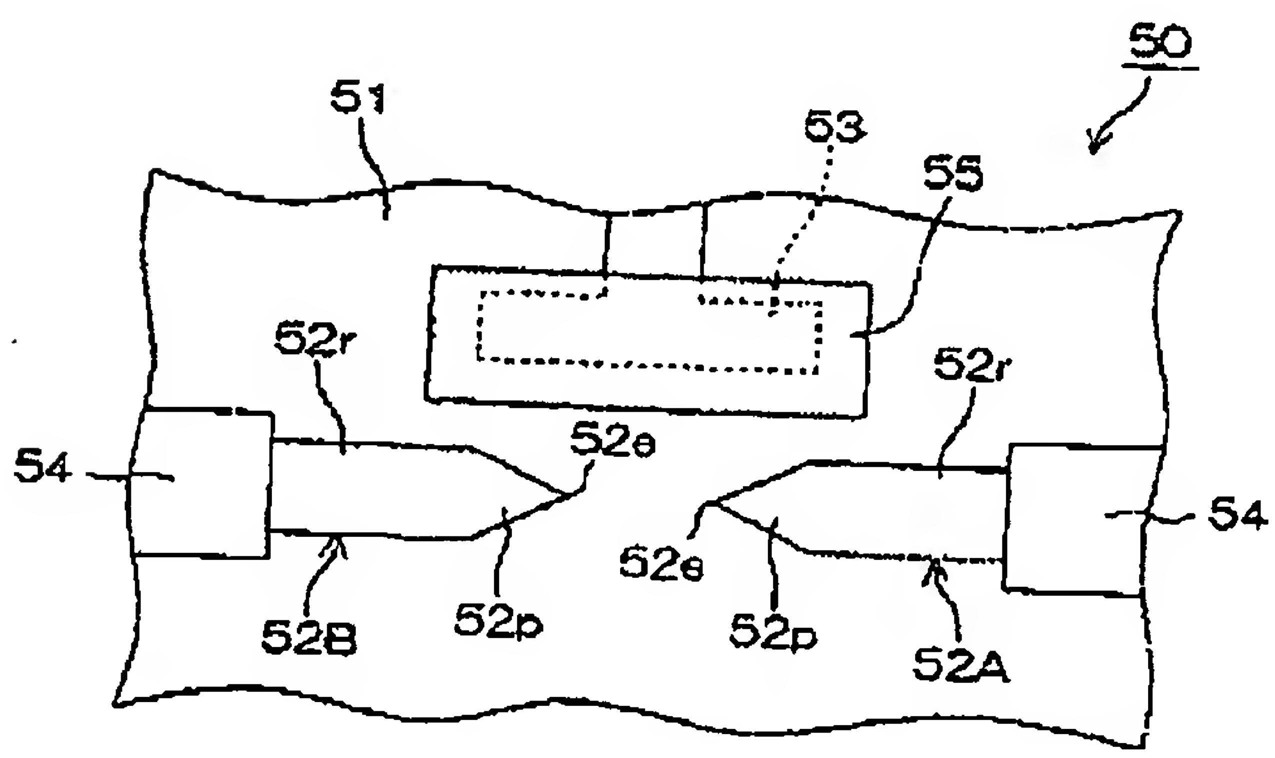

50
51
53
55
52r
52r
52e
52e
54
54
52B
52p
52p
52A

Fig. 11

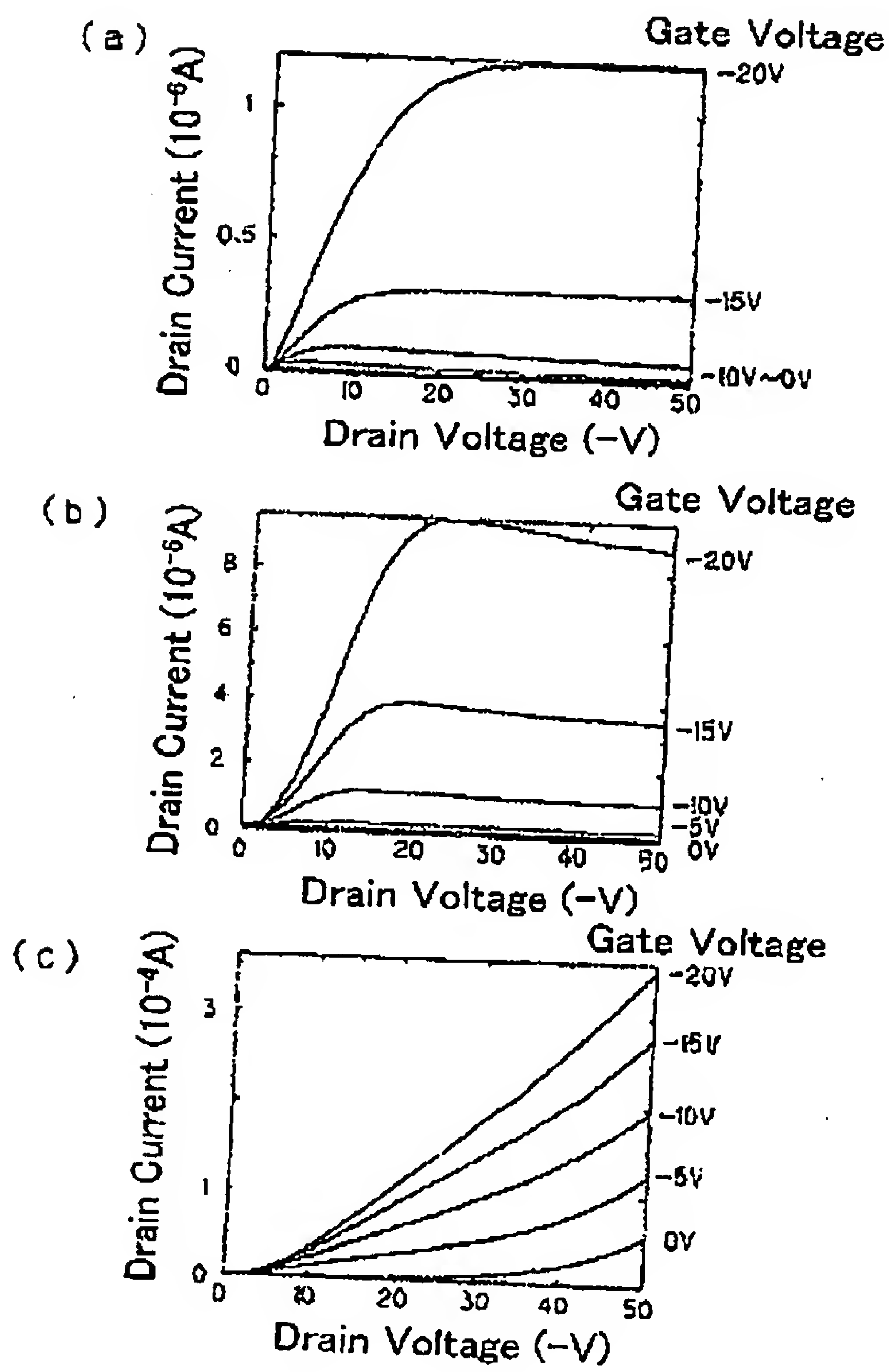

(a)
Gate Voltage
Drain Current (10^{-6}A)
-20V
-15V
-10V~0V
Drain Voltage (-V)
(b)
Gate Voltage
Drain Current (10^{-6}A)
-20V
-15V
-10V
-5V
0V
Drain Voltage (-V)
(c)
Gate Voltage
Drain Current (10^{-4}A)
-20V
-15V
-10V
-5V
0V
Drain Voltage (-V)

Fig. 12

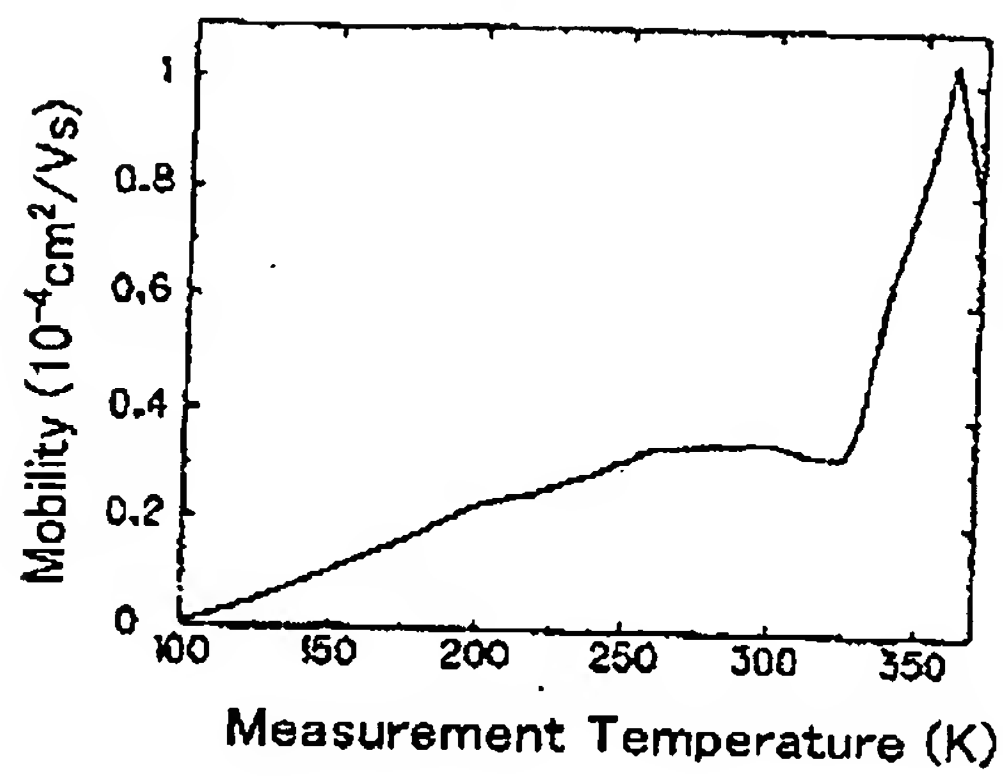

Mobility ($10^{-4}cm^2/Vs$)
1
0.8
0.6
0.4
0.2
0
100
150
200
250
300
350
Measurement Temperature (K)

Fig. 13

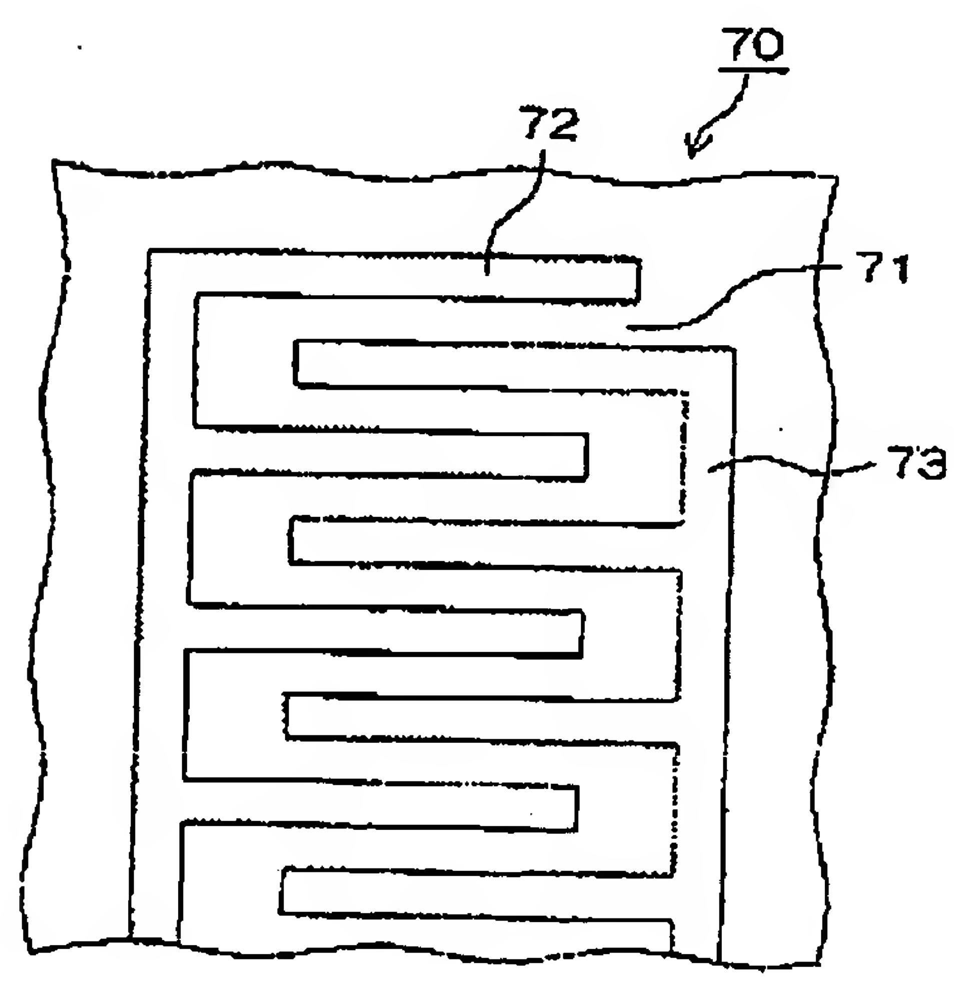

70
72
71
73

Fig. 14